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Effects of Femtosecond Terawatt Laser Pulses on Materials Similar to Porcine Skin*

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ABSTRACT

As the laser technology advances and the availability of high power femtosecond pulsed laser systems increase, the urgency to have damage thresholds and ED50 data on these new laser systems becomes more and more prominent. In this study, we have used >50 mJ, 30-50 femtosecond laser pulses at ~810 nm that produced self-focusing filaments in the atmosphere. Then, these high-powered (1-3 terawatt) filaments were placed on a grid pattern on a piece of chamois. The effects and the damage caused by the filaments were investigated. The results were compared to the damage threshold data. Ultimately, our purpose is to extend this study to porcine skin and to measure Minimum Visible Lesion (MVL) thresholds and to determine the ED50 for exposures at above mentioned laser pulses.
Keywords: Terawatt, femtosecond, near infrared, ultrashort laser pulses

1. INTRODUCTION

Ultrashort (femtosecond), high-powered (terawatt) laser pulses can propagate over long distances in various media. If we consider a gas medium such as air, these short, high-peak power pulses behave very differently than a long continuous wave (CW) laser beam. Nonlinear effects are impressed upon the index of refraction of the medium in which an ultrashort pulse is traveling, forcing the index of refraction of the medium to become a function of the laser pulse. The self-guided filaments are created when the high intensity, ultrashort laser pulse travels through air because of the dependency of the index of refraction of air to the peak intensity of the laser pulse. The index of refraction of air becomes nonlinear over the path that the high peak power laser pulses are traveling. Also, ionized air molecules form a plasma that further influences the propagation of these laser pulses in air. There have been many experiments and observations of the effects of femtosecond, terawatt peak-power laser pulses moving through various media[1,2,3]. Self-focusing and self-guided propagation over long distances, filamentation, creation of plasmas, and generation of multiple wavelengths (300 nm-2 micron) are all results of these laser pulses propagating in the atmosphere. There are many potential applications of propagation of femtosecond terawatt laser pulses in air even though explaining the physics behind some of these observations is incomplete and is not well understood.

In terms of safety considerations, there are necessities to establish some guidelines and to provide updates to the current standards (ANSI Z136.1). Currently maximum permissible exposure levels do not exist for pulse durations shorter than 1 nanosecond. For the near-IR (810 nm), the skin MPE levels are obtained by a few experimental data. This experiment is a preliminary attempt to understand the effects of the ultrashort, high intensity laser pulses on a

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material similar to skin (chamois) before more studies are performed and skin thresholds are established. There exists a single report of thresholds for damage to skin for femtosecond exposure[6]. This study showed a constant radiant exposure below 100 ns for barely perceptible lesions created in skin exposed to single pulses in the visible regime. In the current study, we take a safety risk analysis approach to evaluate the possible reduced radiant exposures required to create skin damage when the possibility for laser beam filamenting is viable.

2. METHODS

In this experiment, we used Ti:Sapphire chirped pulse amplification system (Figure 1.) Our 810 nm, sub 35 femtosecond pulses were produced by a Spectra Physics Tsunami laser system. These pulses were then stretched and amplified by a Ti:Sapphire regenerative amplifier (modified TSA, operating at 1 kHz). The regenerative amplifier was pumped by a frequency doubled 1 kHz Nd:YLF laser[4]. The regenerative amplifier amplified the pulse to ~1 mJ. This pulse was further amplified by a multi-pass amplifier (Terawatt Amplifier System). The Terawatt Amplifier System is designed to increase the TSA regenerative amplifier pulse energy from 1 mJ to ~100 mJ. Te amplifier was pumped by a Q-switched, frequency-doubled ND:YAG laser (Spectra Physics PRO290). The pulse was then recompressed to produce the ~40 femtosecond pulses.

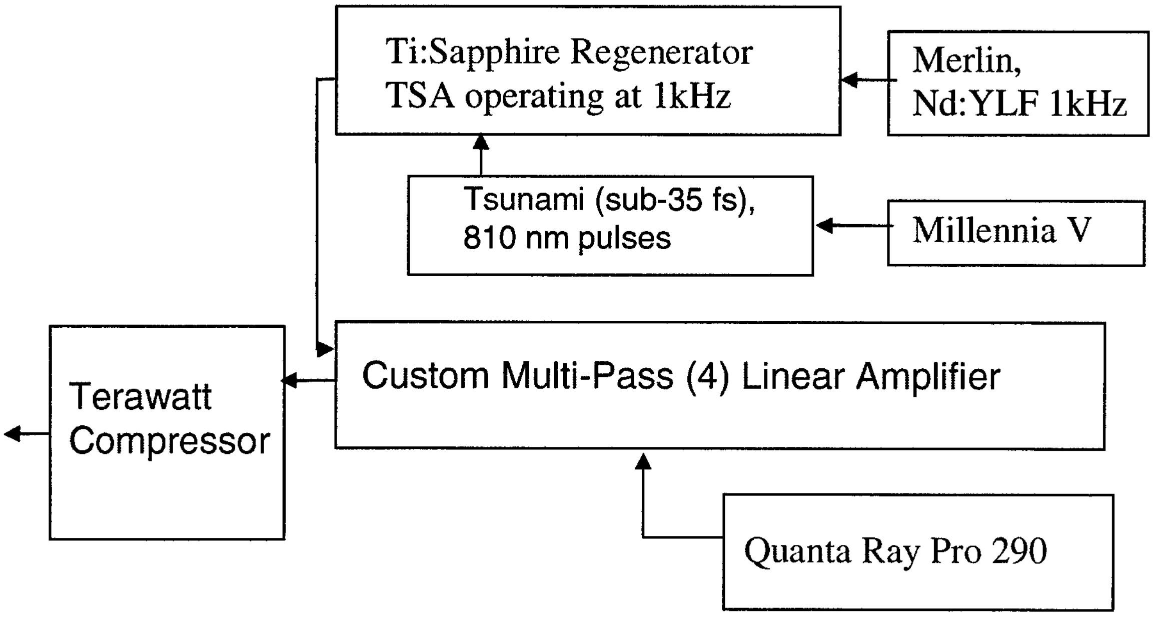

Figure 1: Experimental set up

The beam leaving the compressor was then down collimated using a telescope system consisting of -0.5 m and +1.0 m radius of curvature mirrors (Figure 2). The beam generally produced several filaments propagating through the atmosphere approximately 10-15 meters.

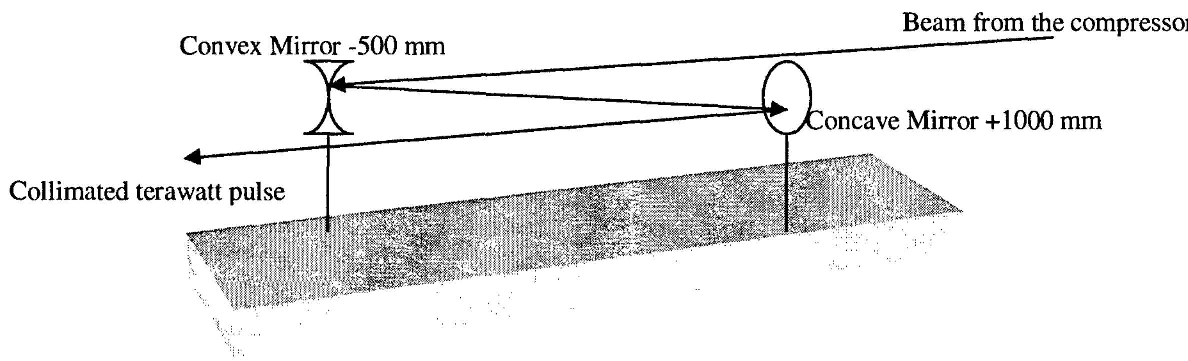

Figure 2: Collimating Telescope

We used a dampened piece chamois to simulate skin. The chamois was placed on a mount and a 1 cm by 1 cm grid was established using a marker (Figure 2).

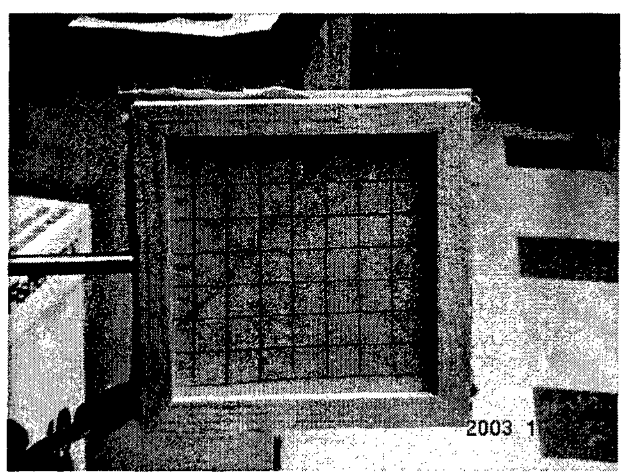

Figure 2. The preparation of chamois for laser exposure.

The terawatt pulses were aligned on the grid using a He-Ne laser. We moved the sample to locate the exposure sites in the grid. We used single pulse and ten pulses at 10 Hz to expose different locations on the grid. We also varied the energy of the exposures from 10 mJ to 80 mJ.

3. RESULTS

We first attempted to quantify the spot size variation for our laser system because of the interesting phenomenology accompanying femtosecond terawatt laser pulse propagation. Because of the extreme irradiances produced, beam diagnostics were demanding. These measurements were made by placing a material sensitive to and that would not destroyed by the large peak powers of the beam. It was found that certain business cards gave a good burn pattern for this laser. We inserted the card into the beam for a single pulse exposure and measured the damage pattern versus distance from the laser system. These patterns were analyzed to determine the spot diameter of the barely perceptible change on the card. It was found that the spot size remained constant to within experimental error for the measurements done. These results are shown in Figure 3.

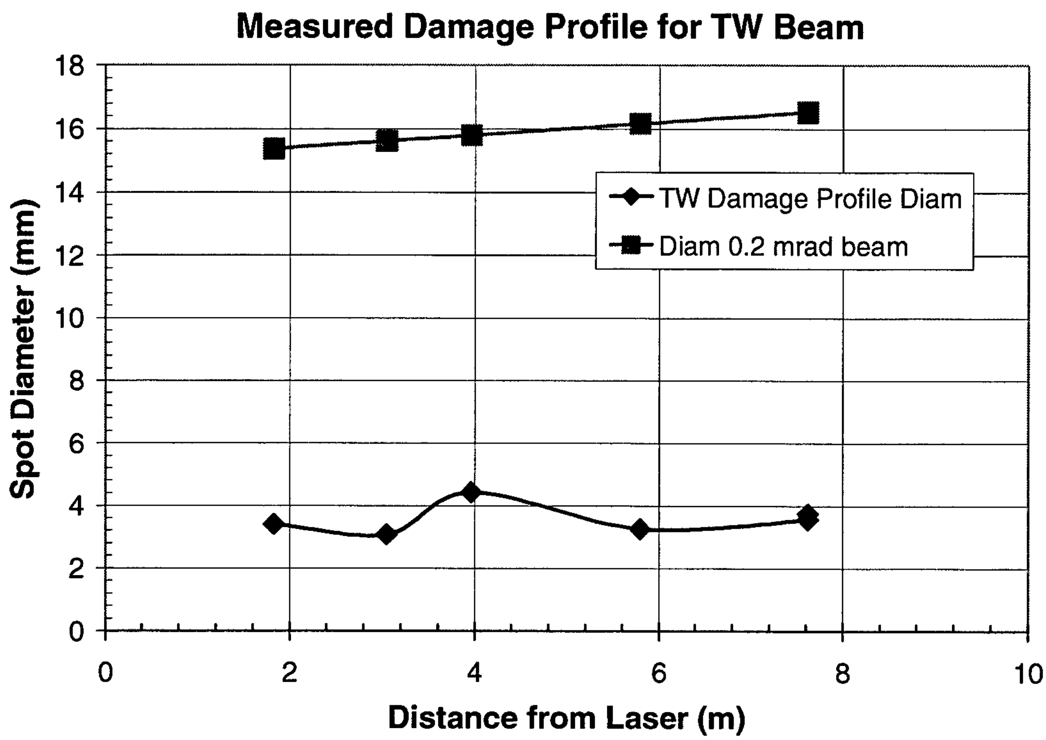

Figure 3. Measurement of damage diameter as a function of distance from the laser (diamonds) and the normal divergence-produced laser beam (squares) for this set up. The energy of the 3 cm spot size beam was measured to be approximately 40 mJ, where the 0.5 cm filament energy was around 8 mJ.

We also investigated the chamois material for damage from our exposures. Table 1 below lists exposure parameters, energies giving damage and shows whether there was a lesion on the chamois.

Pulse Energy (mJ)	Number of Pulses	Distance from the collimating mirror	Visible Lesion
10	1	2 m	No
10	1	4 m	No
10	10	4 m	Yes (very slight)
10	10	4 m	No
15	5	4 m	No
15	10	4 m	No
15	25	4 m	No
15	50	4 m	No
20	1	2 m	Yes (very slight)
20	1	4 m	No
20	5	4 m	Yes (very slight)
20	10	4 m	Yes (very slight)
20	25	4 m	Yes (slight)
20	50	4 m	Yes (slight)
20	10	2 m	Yes (slight)
40	1	2 m	Yes (defined)
40	1	4 m	Yes (slight)
40	10	2 m	Yes (defined)
40	10	4 m	Yes (slight)
50	1	2 m	Yes (defined)
50	10	2 m	Yes (deep)
55	1	4 m	Yes (defined)
55	10	4 m	Yes (more defined)
60	1	2 m	Yes (deep)
60	10	2 m	Yes (deeper)
80	1	2 m	Yes (deepest)
80	10	2 m	Yes (most damage)

Table 1. Exposure parameters for the target at two different locations in the beam path

4. DISCUSSION

When high intensity laser pulses are traveling in the atmosphere, the most noticeable and overpowering occurrence is the creation of self-guided filaments. Normally, laser beams diffract and the beam size will diverge if there is no optics involved in the beam path. When the terawatt laser pulses are traveling through atmosphere, however, they affect the refractive index of air in such a way that the index continuously changes leading to a continuous filamenting of the laser pulses. There exists a laser power threshold value for air where pulses will remain at a constant size indefinitely. This threshold value is about 2 gigawatts[5]. Theoretically, above the threshold value, the beam will converge and decrease in size until it collapses. However, the plasma formation due to breakdown of air creates a defocusing effect. These two opposite phenomena generally balance each other leading the way to a long lasting beam filament. We have found that this is a significant event to consider in safety analysis.

5. CONCLUSIONS

We have measured the damage threshold for a skin stimulant exposed to femtosecond terawatt laser pulses. The damage occurred due to the high radiant exposures produced for a very long propagation distance. We recommend that further analysis be done to determine when filamenting occurs as a function of wavelength and pulse duration to assure a complete hazard analysis will represent the worst-case to provide safety for those working with these laser systems.

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